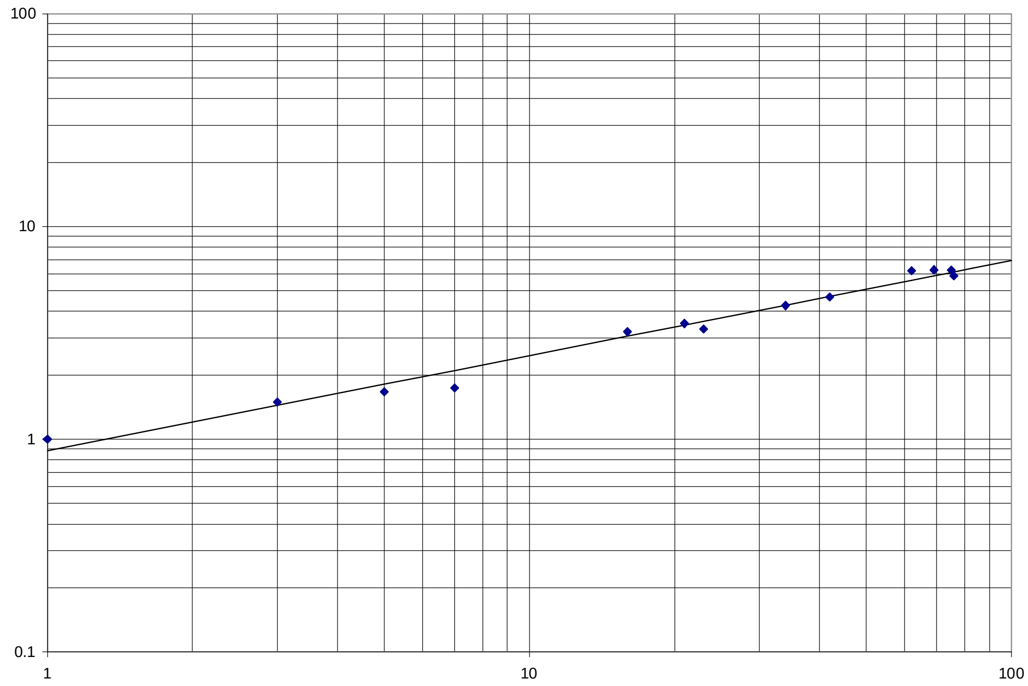
RELIABILITY GROWTH



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Reliability Growth

- **The improvement in a reliability figure of merit (MTBF, MMBF, λ etc.) caused by successfully learning about and correcting of faults in a products design, use or manufacture. This is accomplished through planned testing, and problem identification and removal (TAAF), etc.**

Benefits

- Provides a metric to evaluate the improvement in design and manufacture of a product.
- Aids in evaluation the corrective action program on equipment.
- Provides an effective quantitative measurement of the effectiveness of the reliability program.
- Used as an oversight/program management tool.

Objective

- Be able to answer or perform:
- What is the basic approach methodology to reliability growth models?
- Apply and understand the Duane reliability growth model.
- Understand the AMSAA reliability growth model.

Outline

- **Background**
- **Reliability Growth Mathematics**
- **Modeling Strategy**
- **Duane Reliability Growth Model**
- **Army Material Systems Analysis Activity (AMSAA) Reliability Growth Model**

Background

- New products (except prototypes) have often been less reliable during early development and early production.
- Tests and service brings to light problems which are analyzed, corrected and incorporated into subsequent production runs (or incorporated into all models as a result of warranty campaigns, recalls etc).
- Therefore products exhibit reliability growth.
- This was first "formally" analyzed by J.T.Duane.
- It was found that the log (cumulative failure rate) vs. log (cumulative time) is linear.

Reliability Growth Mathematical Relationships

$$\lambda_c = F_c / (t_{test}) = kt^{-\alpha}$$ ***where:***

λ_c ***= cumulative failure rate*** **= tot. failure/tot. hrs.**

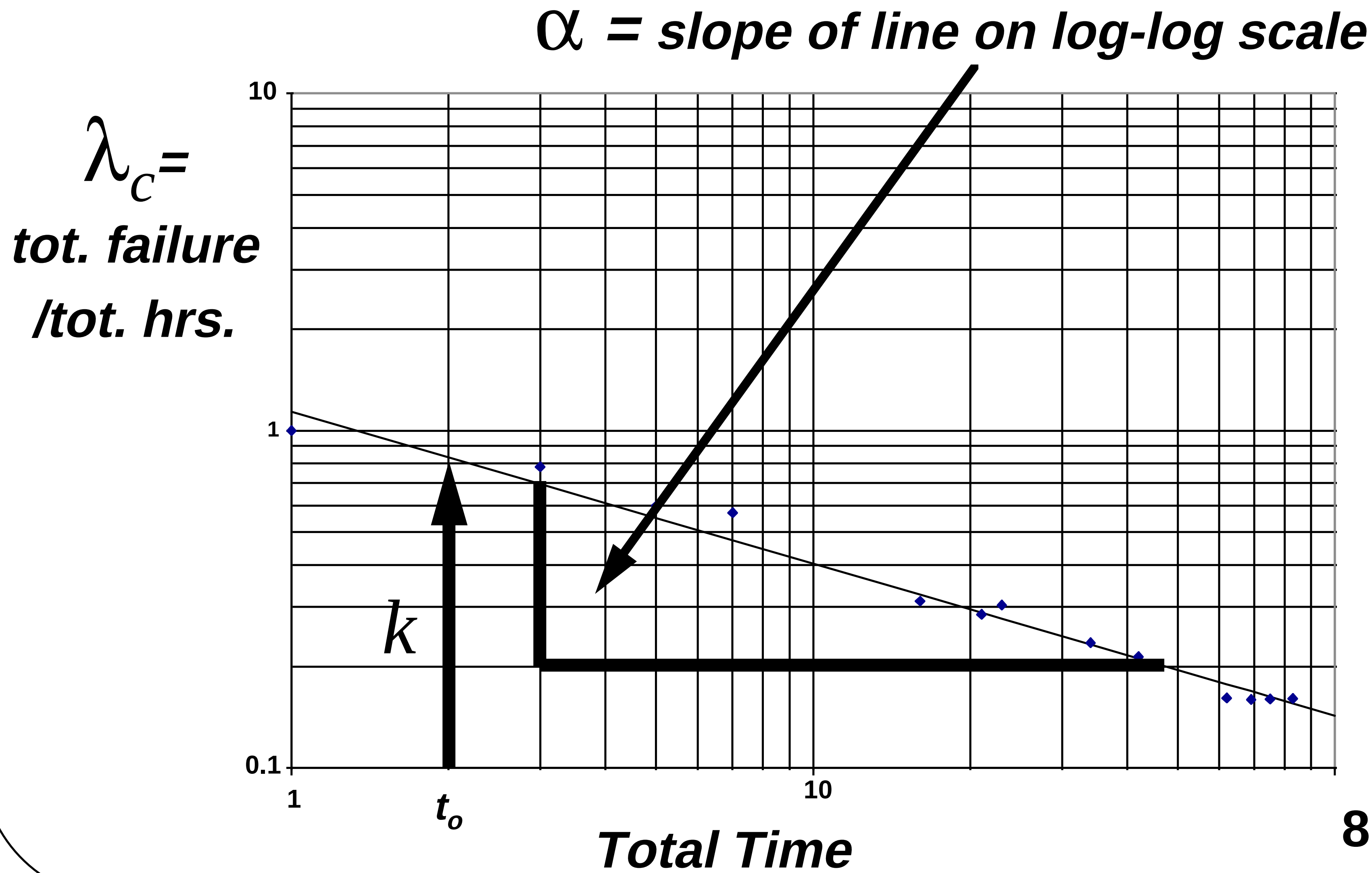
F_c **= cumulative failures**

t_{test} ***= tot. test hours***

α ***= growth rate (slope of of line on log-log scale); a function of equipment complexity, design.***

k ***= constant; a function of complexity, design life, reliability standards, etc.***

Reliability Growth Mathematical Relationships



Reliability Growth Mathematical Relationships

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Also instantaneous, λ_i , rate is given by:

$$\lambda_i = (1-\alpha)\,\lambda_c$$

similarly instantaneous MTBF, $MTBF_i$ is given by:

$MTBF_i = 1/\lambda_i$ **and** $MTBF_c = 1/\lambda_c$ **therefore:**

$$MTBF_i = MTBF_c / (1- \alpha)$$

where $MTBF_c$ = cumulative MTBF

Reliability Growth Mathematical Relationships

(continued)

$$\log (MTBF_c) = \log (MTBF_{c0}) + \alpha \log (t - t_0)$$

where

$MTBF_c$ **= cumulative MTBF**

= total hours / total failures

$MTBF_{c0}$ **= initial cumulative MTBF**

t **= time**

t_0 **= initial time**

α **= growth rate or slope of line.**

Duane Model

- Learning curve approach
  - Lessons learned should result in reliability growth
- Continuous Model
  - Used to monitor failure rate vs. time
- Developed to monitor growth during TAAF phase

Fundamental Assumption of Duane

- **Reviewing formulas we have:**

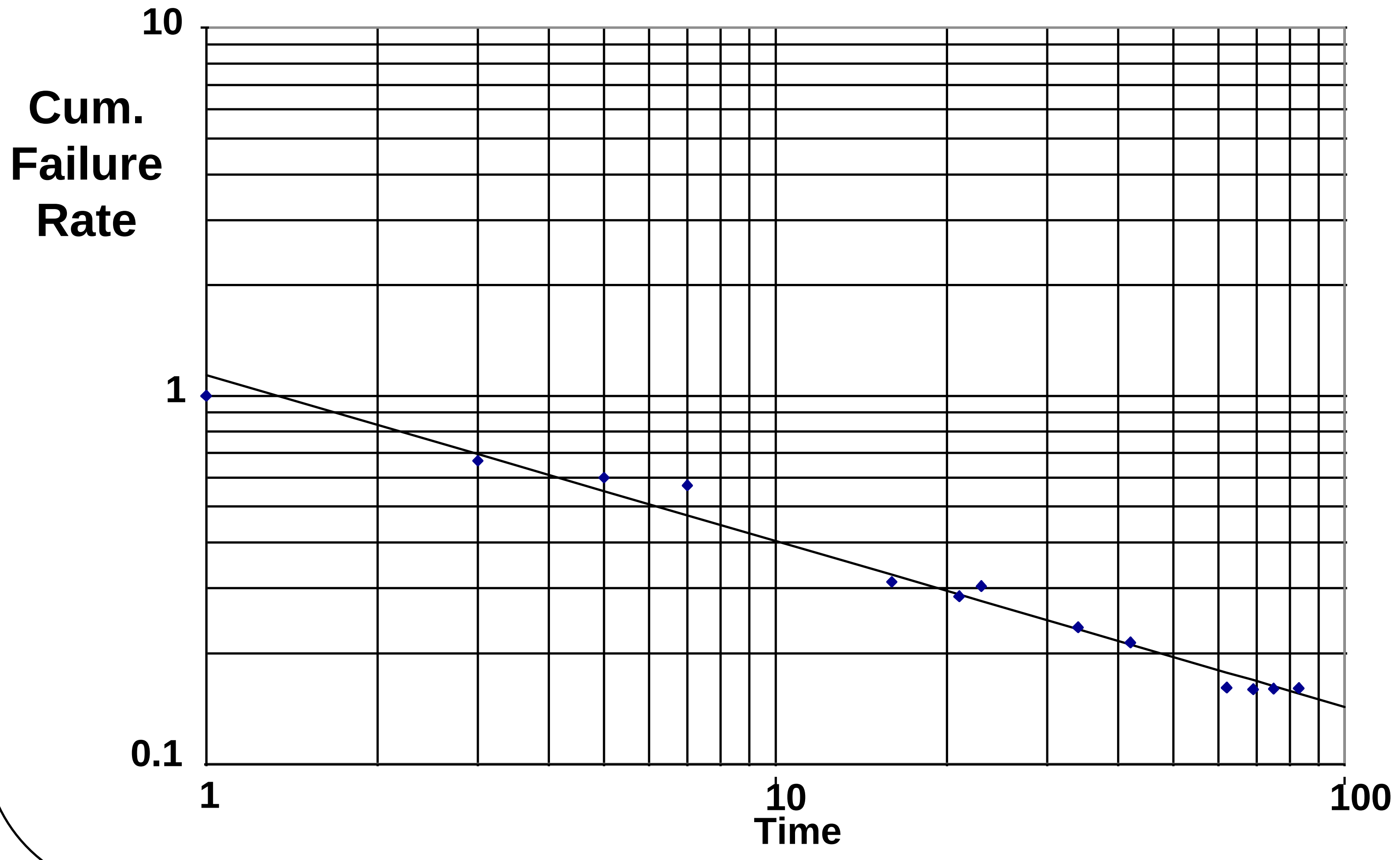
$$\lambda_c = F_c /(t_{test}) = kt^{-\alpha}$$

$$MTBF_c = 1/\lambda_c \text{ and } MTBF_i = 1/\lambda_i$$

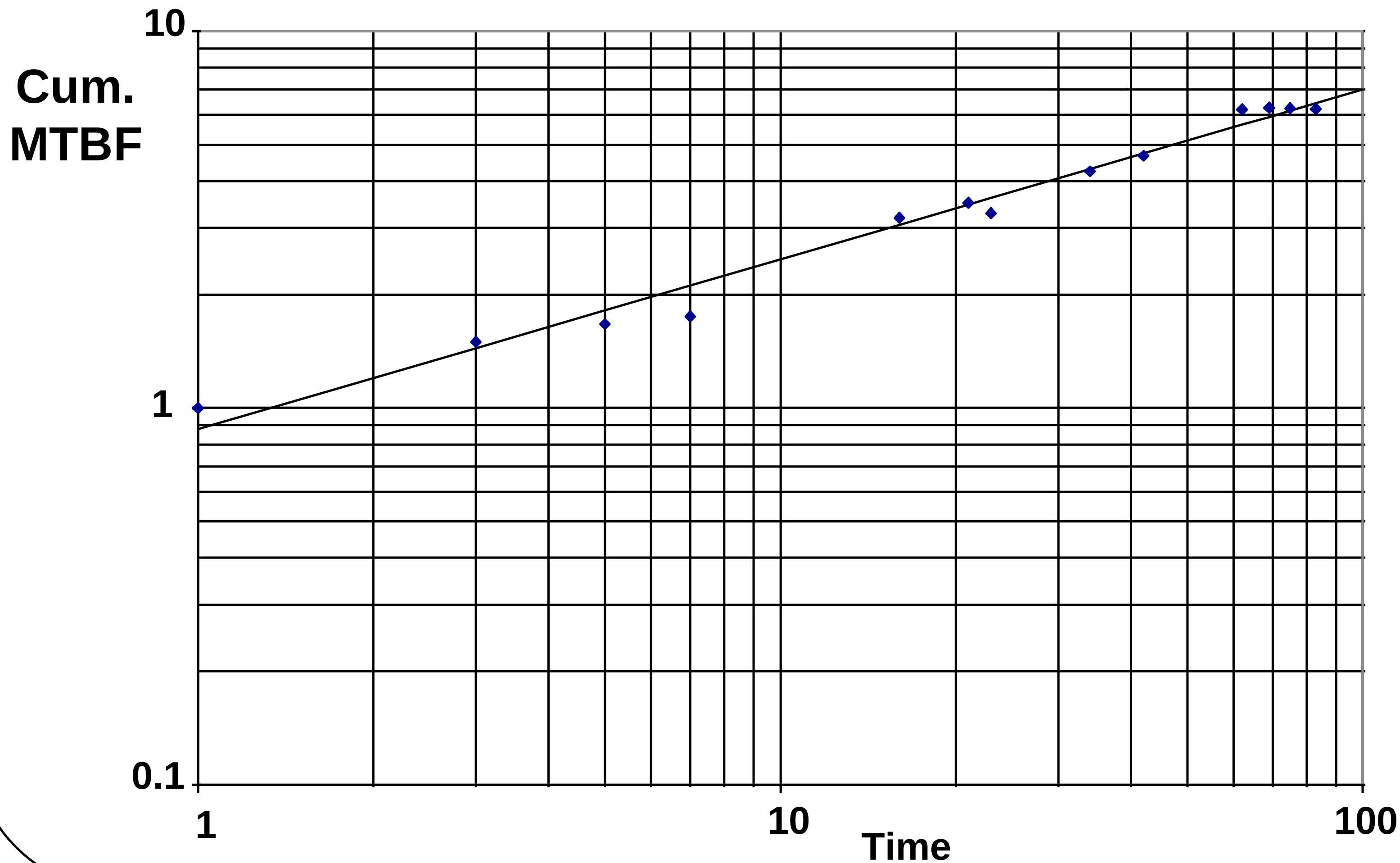
$$MTBF_i = MTBF_c / (1 - \alpha)$$

$$\log(\lambda_c) = \log(k) + -\alpha \log(t)$$

Duane Model Plot



Positive Slope Duane Plot



Performing Reliability Growth Analysis -- Current Data

- **Use MTBF (the line goes up instead of down)**
- **Plot the raw achieved MTBF for each test sample. It helps people grasp the concept if they see raw data.**
- **Plot Cumulative MTBF vs. total test time and draw a best fit line through the data.**
- **Estimate the reliability growth slope.**
- **As soon as a reasonable chart line can be found, plot the instantaneous MTBF**
- **Extend the chart line for a forecast.**

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AMSAA Model

Continuous model

- Normally used to monitor failure rate vs. time
- May be used on “one-shot” Items
  - Large sample required

Used to monitor reliability growth during TAAF

- Method developed to see effects of design changes over short duration.

AMSAA Model

- **The intensity function can be approximated by the Weibull failure rate function:**

$$\rho(T) = \lambda \beta t^{\beta-1}$$

where: $\rho(T)$ = cumulative failure rate

λ > 0, scale parameter

β > 0, shape parameter

t = cumulative test time

AMSAA Model

- The maximum likelihood method for time truncated test provides a point estimate of as follows:

$$\beta = \frac{N}{N \ln(T) - \sum_{i} \ln(X_i)}$$

Where: N = number of failures

T = cumulative test time

X_i = time of failure

i = 1 .. n

AMSAA Model

- For small sample sizes it is recommended that the unbiased estimator of Β be used:

$$\beta_{unbiased} = \frac{N-1}{N}\beta$$

AMSAA Model

- The point estimate of the scale parameter is determined by:

$$\lambda = \frac{N}{T^{\beta}}$$

where: N = number of failures

T = cumulative test time

λ = scale parameter

β = point estimate or unbiased estimator

AMSAA Model

- **The point estimate $\rho(T)$ is calculated by:**

$$\rho(T) = \beta \frac{N}{T}$$

Where:

$\rho(T)$ **= point estimate of intensity function**

β **= point estimate or unbiased estimator**

N **= the number of failures**

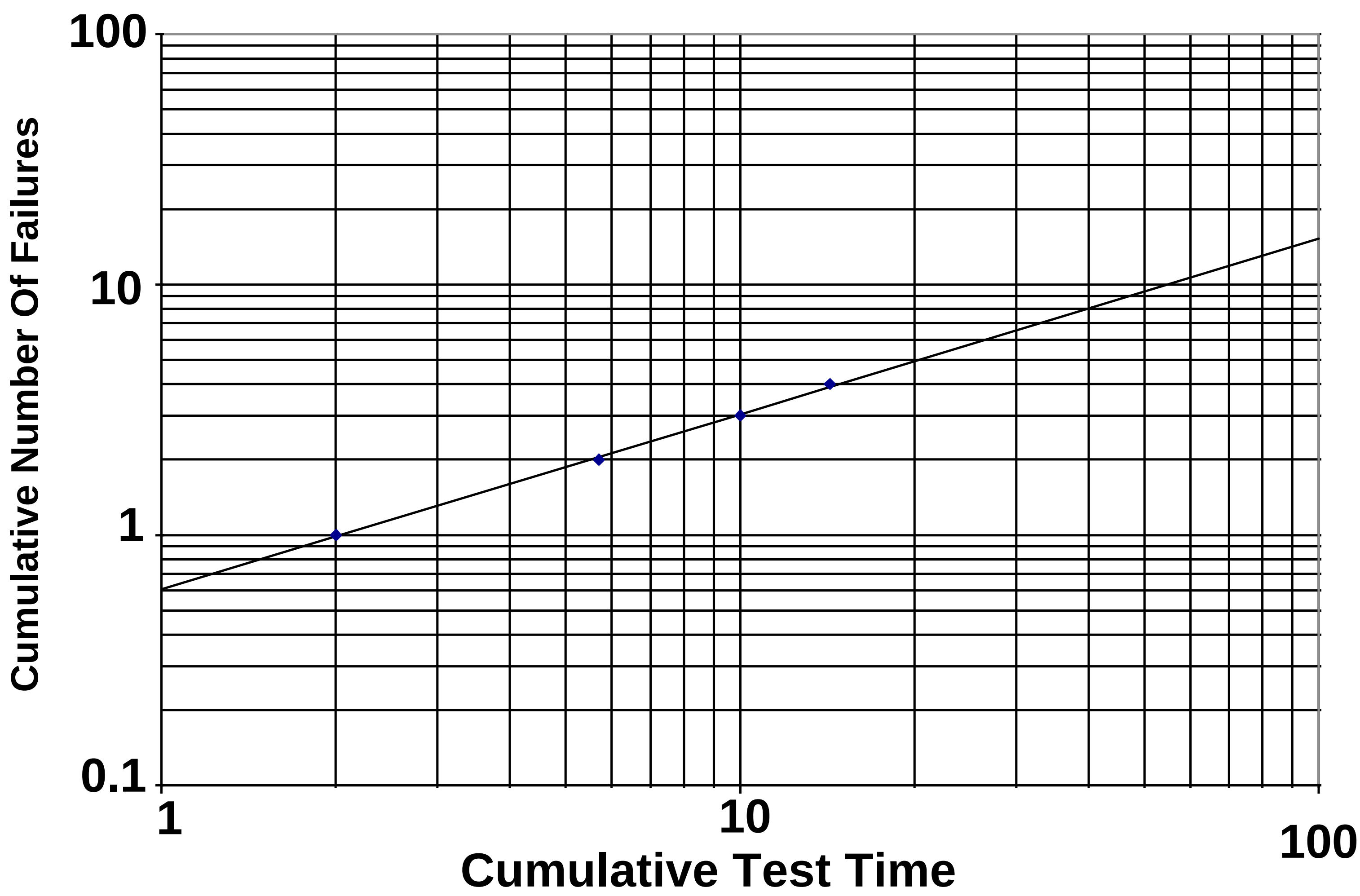
T **= the total test time**

AMSAA Model

- The point estimate of the Reliability is equal to 1 - $\rho(T)$ A confidence interval can be found for reliability based on the number of failure points and interval desired as was found above for MTBF.

$$1 - \frac{1}{MTBF_{(L)}} \le 1 - \rho(T) \le 1 - \frac{1}{MTBF_{(U)}}$$

AMSAA Cumulative Failure Plot



Conclusions:

- Reliability Growth Analysis is an effective means to measure the reliability and design improvement effort.
- Cumulative MTBF (or MMBF) is plotted against total test time on a log - log scale which plots as a straight line.
- The slope of the line can be an indication of the reliability effort.
- The Duane Model is a continuous reliability growth model used to monitor failure rate vs. time. It was developed to monitor growth especially during TAAF phase.
- The AMSAA model is also a continuous model often used to monitor failure rate vs. time. It is especially effective during TAAF and over short durations.
- The AMSAA model may be used on "one-shot" Items but a large sample required.

Additional Information

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Find the Growth Rate of an Experimental Sensor:

Test Hours	Failure Number	Cum. λ	Cum MTBF
8	1	________	________
31	2	________	________
63	3	________	________
88	4	________	________
152	5	________	________
198	6	________	________
242	7	________	________
355	8	________	________
458	9	________	________
579	10	________	________

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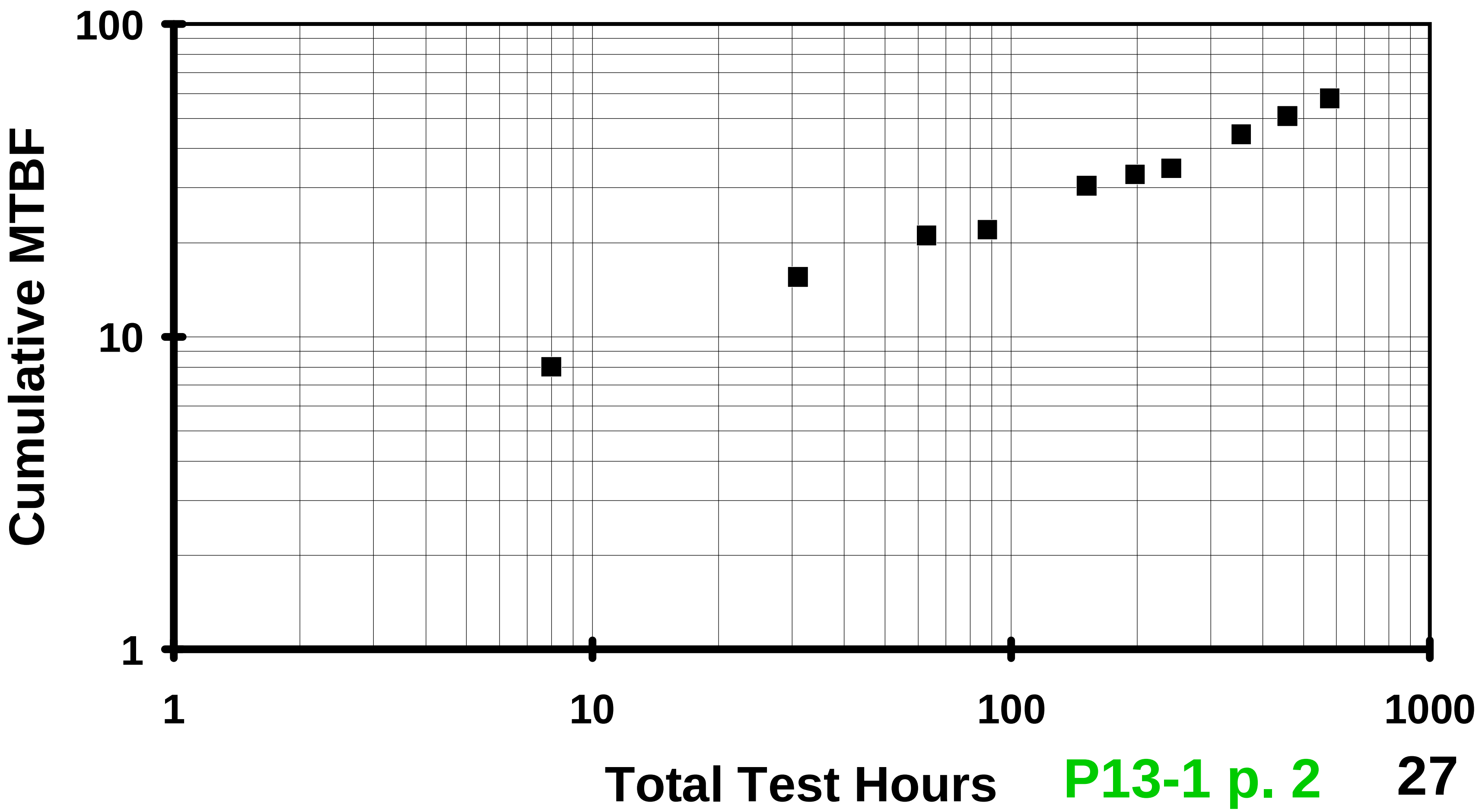
Sensor Reliability Growth



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Find the Reliability Growth of the Following Missile:

Cum. Missions	Fail No.	Cum. λ	Cum MTBF
1	1	________	________
3	2	________	________
4	3	________	________
7	4	________	________
16	5	________	________
21	6	________	________
23	7	________	________
34	8	________	________
42	9	________	________
62	10	________	________
69	11	________	________
75	12	________	________
76	13	________	________

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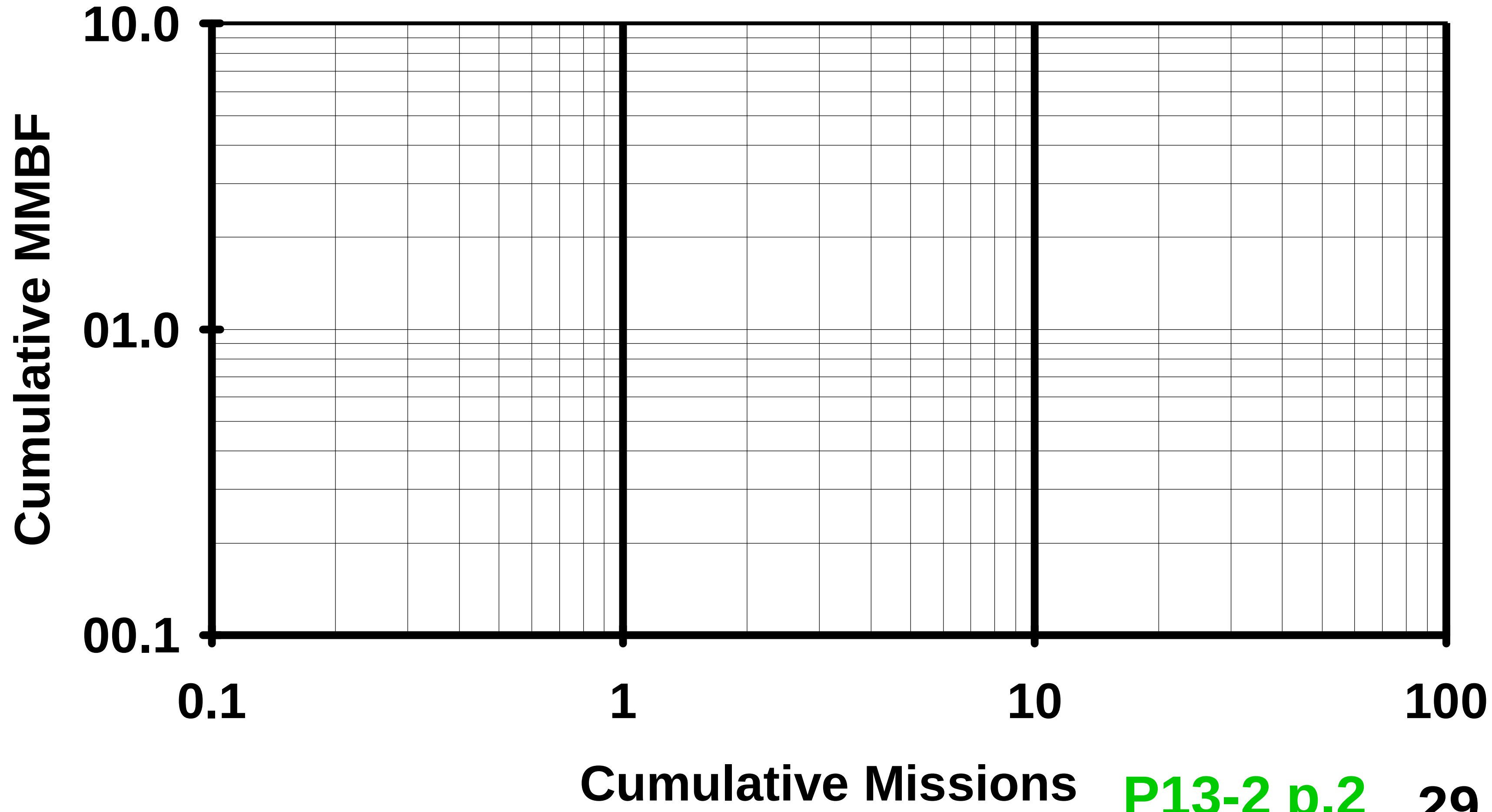
Missile Reliability Growth



Reliability Growth Mathematical Relationships
(continued)

also:

$$\lambda_i = (1\text{-}\alpha)\,\lambda_c$$

where:

λ_i **= instantaneous failure rate**

This can be shown from:

$$\lambda_i = \lambda(t) = \lim_{\Delta t_{test} \to 0} (\Delta F_c / \Delta t_{test}) = \delta F_c / \delta t_{test} = (1\text{-}\alpha) k t^{-\alpha}$$

$$\lambda_i = (1\text{-}\alpha)\,\lambda_c$$